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OVERLAND MOBILITY OF THE FORCES IN THE CANADIAN  
ENVIRONMENT(U) DIRECTOR SCIENTIFIC INFORMATION SERVICES  
OTTAWA (ONTARIO) J OWENS 14 JAN 77

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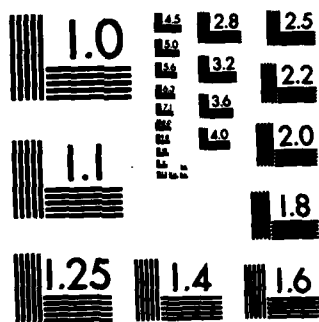
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OVERLAND MOBILITY OF THE FORCES  
IN  
THE CANADIAN ENVIRONMENT

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JOHN OWENS

ENGINEER

STUDY

THE OVERLAND MOBILITY OF THE FORCES IN  
THE CANADIAN ENVIRONMENT

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## THE OVERLAND MOBILITY OF THE FORCES IN THE CANADIAN ENVIRONMENT

### INTRODUCTION:

1. A review of Canadian activities in the field of development of military vehicles reveals a relatively low rate of success in producing equipment to meet the needs of the Forces. The reasons for failure vary from project to project and include economic, financial and managerial factors coupled with a tendency to pursue too far the fulfillment of unrealistic operational requirements. A highly significant factor common to all development projects has been the absence of a sound technological base from which to embark on the development process. \*
2. This deficiency has been observed from time to time and, in certain projects, development of basic technology was undertaken in parallel with the equipment development program. As may be expected these parallel programs rarely succeeded because the output from the basic development was not available in time to influence the equipment development project.
3. Past failures have generated an antipathy towards equipment development programs and this is expressed in the resolve to buy the vehicles needed by the Force to meet its various commitments from commercial or foreign sources. This procedure has considerable validity in the short term, in the long term, however, it may prove both costly and inefficient to the point of danger. There is

no assurance that, in the process of manufacturing vehicles for commercial users, Canadian industry will develop a technology which will enable them to meet the needs of the Canadian Forces. The traditional foreign suppliers are concerned primarily with the needs of their indigenous forces who operate in a very different physical environment from that found in Canada and will tend to optimize designs to meet their national requirements rather than those of the Canadian Forces. To ensure an acceptable degree of operational mobility in the Canadian environment the Canadian Forces must develop a technology which will enable equipment suppliers to provide vehicles to meet their requirements.

4. The provision of a capability for mobility in the Canadian environment involves particularly difficult problems. There is very little equipment available from any source and the technology is incomplete and scattered. This applies particularly in the case of smaller vehicles.
5. There is an interplay between requirements and technology in that the existence of a requirement stimulates technological advance and technological advance stimulates the development of requirements. This study is concerned with the development of technology. While this is obviously closely related to the development of the equipment to which it relates it has the broader aim of promoting an understanding of the technology by users and engineers alike so that the process of formulating requirements and specifications, evaluating equipment and conducting or influencing development activities may be soundly based.

SECTION 1

BACKGROUND

1. The requirements of the Canadian Forces for equipment to provide an acceptable degree of overland mobility are determined by the roles of the force. These are set out in various official documents and include:
  - a. operations in support of the NATO alliance;
  - b. operations to maintain national sovereignty, and
  - c. operations in support of UN peace keeping activities.
  
2. This study is concerned primarily with technology for equipment for maintaining national sovereignty and for operations in support of the NATO northern flank. In its role in support of NATO operations in central Europe where the Force operates in a relatively conventional fashion the equipment necessary to provide the required degree of mobility is probably best obtained from those allies which have similar operational requirements coupled with very much larger quantitative requirements. There will be some exceptions from this general case where the balance between the primary and secondary roles of the co-operating forces is widely different and these must be considered in a case by case basis.
  
3. The conduct of land operations within Canada and on the NATO flank in Norway imposes a set of operating conditions which are entirely different from those in Central Europe. In general the mobility of vehicles designed for operation in temperate zones diminishes

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as the scene of operations is shifted northwards in Canada. It drops to near zero in the treeline region and rises somewhat again in the barren. There are, however, some massive obstacles in the barren lands which severely restrict mobility of any type of over-land vehicle.

4. It appears, therefore, that if the Canadian Forces are to be capable of conducting sustained operations of company groups or larger over an area stretching from about 200 miles south of the treeline and northwards to the limits of Canadian sovereignty vehicles designed specifically for operation in this environment will be required.
5. There are few countries which have similar requirements. Sweden has an abundance of heavily timbered terrain in which conditions are similar to some areas of eastern and western Canada. The Soviet Union has vast areas in which conditions are similar to those in North-central Canada and the United States has a limited interest centred principally in the Western Arctic where rather specialised conditions prevail. None of these countries is likely to afford a very fruitful source of technology directly applicable to the Canadian problem and if the Canadian Forces want to achieve mobility in the Canadian North they are going to have to provide their own technology and very probably their own equipment.
6. While it is possible to state the requirement for mobility in the geographic area in general terms there is difficulty in producing

a specific statement in terms of terrain and vehicle parameters which will form the basis of concept formulation and evaluation. It is clear that without such a descriptive system the process of design and development will remain an arbitrary and expensive cut and try process with the reasons for success or failure frequently masked by extraneous factors. The starting point therefore for any systematic technology base must be the definition of mobility requirements. When this is done the examination of factors influencing mobility may be commenced.

7. Implicit in the concept of developing a technology base is the examination of the existing "state of art" and the institution of activity to bring it to the level required. The 'state of art' in so far as it exists takes the form of published literature and data and is normally gathered together in libraries or data banks. A 'state of art' data base is the essential component of a technology base and to some extent the terms are synonymous. It follows that a 'state of art' data base must be established early in the development of a technology base.
8. Canada possesses an active off road vehicle industry which provides equipment for commercial use in northern regions. The industry produces a range of vehicles which have not shown a very marked development over the past twenty years and there is little indication that the industry is oriented to new product development. Its potential to meet military requirements needs to be established.

9. Any program designed to enable the Canadian Forces to achieve mobility in the Canadian environment must first establish the mobility requirement and then define a state of art data base. A program of work to augment the data base must be worked out and the ability of industry to assist must be determined.

## SECTION 2

### AIM

To define a program to provide the technology base required by the Canadian Forces to achieve mobility in the Canadian environment.

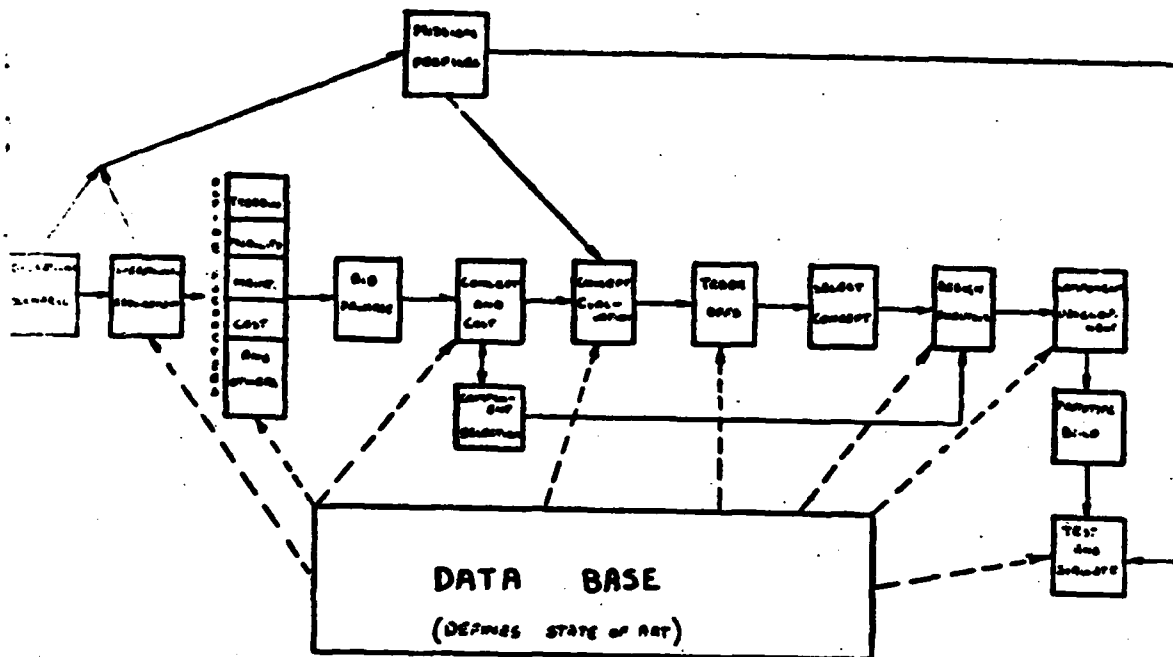


FIG. 1 TYPICAL DEVELOPMENT PROCESS

SECTION 3

THE VEHICLE DEVELOPMENT PROCESS

1. The activities involved in the typical vehicle development process are set out in Fig 1. The diagram expands the steps between the formulation of the operational requirement and the selection of a concept and tends to compress the activities beyond this point. This has been done to emphasise the importance of the early stages of the process and avoid unnecessary complication in the display.

2. The Operational Requirement

The process starts with the definition of an operational requirement which sets out the characteristics of the equipment as visualised by the user and explains its application. Typical of operational requirements for vehicles in the category under consideration is that for the Medium Marginal Terrain Vehicle for the 1980's (MMTV 80) (1), which states in part: "A high degree of mobility over all types of marginal terrain including deep snow, sand, muskeg, swamp, rock strewn soil and areas of light tree cover is essential. Emphasis in design, however, will cater for conditions which are most prevalent, winter and summer, in areas of the Canadian North and North Norway-----. The vehicle must show a marked improvement over current military vehicles in slope climbing, slope traversing and deep snow performance."

3. This statement, in broad and very general qualitative terms may well be a fair reflection of the desires of the operational user of the equipment, it is however, insufficiently precise to form the basis of either a development program or a program to determine the suitability of candidate vehicles.

4. Defining Parameters

The first step which must be taken is to identify the terrain and related performance parameters in precise and unambiguous terms which can be understood and agreed by users, engineering staffs and development agencies. The parameters when identified must be suitable for embodiment in the specification which will be used to control the development and/or evaluation of concepts or candidate equipment.

5. The problem is essentially that of establishing a means of communication so that users, DND engineering and test staffs and potential contractors are able to communicate in a single precise language which is clearly understood by all. This may appear to be a somewhat simplistic statement, however, the discussion which took place at the bidders conference on the MMTV 80 and problems with development projects in several countries amply illustrate the difficulties which arise from failure to express the requirements in a manner which can be understood by development contractors.

6. Mission Profiles

An overall operational scenario is assumed to have existed and to have been used in drafting the operational requirement. The terrain and performance parameters which have been developed specify the detailed requirements for the equipment and a series of mission profiles covering specific operations in limiting and sub-limiting conditions is required to provide the framework of the concept evaluation process. The mission profiles should emerge naturally from the operational requirement and are used both at the concept evaluation stage and later during test and evaluation. They should, in fact, form the basis of the user trials to be conducted later in the development program.

7. Bid Package

The performance, terrain, mobility and other pertinent parameters, together with the mission profiles are important elements of the bid package which is passed to potential development contractors. From this information and other technical data the contractor formulates his approach to the problem.

8. Concept Formulation

The response of potential development contractors to the bid package is normally in the form of a design concept or concepts accompanied by the supporting data called up in the bid package. The detail contained in the concept and the extent and validity of the supporting data may be expected to vary considerably between

contractors and may depend upon whether or not the concept formulation phase is funded. The conceptual proposal, however, must contain all the information which is required in the concept evaluation stage.

9. In formulating the concept the contractor must define the form of the vehicle and make a preliminary selection of components to be used in the development process. Apart from the specification of certain items of hardware or minor components which may be contained in the bid package in the interests of standardization this is the first point in the process at which hardware is specified.

#### 10. Concept Evaluation and Trade Offs

The aim of the process to this point has been to produce equipment concepts which may be evaluated against the requirements and ranked in order of merit. There is a wide range of parameters which must be considered in this process and comparative analysis of these may be conducted by the use of matrices for each contributing factor or group of factors, supported by mathematical modelling where appropriate. The credibility of such analyses depends upon the validity of the input and a critical review of each contractors proposal is essential.

11. The evaluation techniques must allow the input of trade off criteria in the fields of cost and performance and assessment of the impact of these on candidate ranking.

12. The main thrust of the present study is in the area of mobility and it is essential that the input from the contractors in this area takes a form which will allow comparison by analytical means and appraisal of the impact of trade offs.

13. Design Analysis and Component Development

The selection of a concept(s) for development is made on the basis of the concept evaluation. The component selection during the concept formulation is based upon a projection of state of art as it will exist following further development. The first step in the development process is the conduct of a detailed design analysis and the formulation of a component development activity to realise the projected state of art improvement. There is obvious feed back from this analysis into the concept evaluation process.

14. Test and Evaluation

The prototype vehicles which are built during the development are the expression of the concept in terms of practical hardware. Tests are conducted to determine, among other things, the performance of the prototypes. It is essential that, in designing the test program and selecting the test facilities, the environment created is that defined in the mission profiles and specified in the bid package, modified if necessary by experience gained during concept evaluation and development. The evaluation of test results should compare predicted performance with that realised and explain differences. A decision on acceptance or rejection or further development

is made on the basis of these deliberations.

15. Data Bank

It is obvious that throughout the development process there is need to refer to prior knowledge and this is typified by the examples of data bank input in Fig 1. The data which is used may be broadly classified as common knowledge, as typified by the action of a simple wheel rolling on hard pavement, or state of art as typified by the action of a pair of oblate wheels driving in weak soil. It is unwise to believe that common knowledge embraces any significant state of art information and the existence of a data bank from which state of art information on any aspect of the development program may be easily withdrawn is vital to success.

16. Discussion

A simplified overview of the development process has been presented. It should be noted that the process of concept evaluation may be applied to existing hardware offered against known military requirements. The application of such an evaluation should be mandatory before a decision to buy and try is taken.

17. The component selection and development activities have been highlighted because component development can, and does, exist as a separate activity. For this activity to provide the best value for money and effort, however, it is necessary that it be conducted within the framework of a predetermined vehicle concept.

18. Consideration of the development process reveals a need for:

- a. a means for defining terrain characteristics and vehicle parameters so that performance of a concept may be predicted,
- b. a knowledge of the ability and potential of Canadian Industry to participate in the development process,
- c. a readily accessible data base bearing on all aspects of state of art in vehicle design, and
- d. a standardised test environment compatible with the terrain parameters defined in the requirements definition stage.

These will be discussed later in the study.

SECTION 4

TERRAIN CLASSIFICATION AND MOBILITY PREDICTION

1. There is a need, in the process of development or evaluation of vehicles designed for high mobility, to define the terrain characteristics in a form which will allow the prediction of the mobility of a conceptual design.
2. Great difficulty has been experienced in arriving at an agreed definition of mobility and many groups of experts have derived hundred of hours of innocent enjoyment out of manipulative semantics seeking a definition. There is now general agreement that the maximum speed made good by a vehicle between two points in a given terrain is a suitable measure of its intrinsic mobility in that situation. (2). The factors which emerge from this definition as governing mobility are:
  - a. the environment created by the terrain.
  - b. the design characteristics of the vehicle, and,
  - c. the mission to be accomplished.
3. It is to be noted that these same characteristics emerge from other definitions of mobility and any system of comparing or evaluating the performance of vehicles must therefore provide for a means of estimating or measuring the success of the vehicle in performing the mission in the environment created by the terrain. It should also desirably reveal the design features which limit or inhibit the completion of the mission.

4. There are three principal systems of terrain classification (or description) and vehicle mobility prediction in use at present. They are:

- a. correlative systems,
- b. the US developed AMC 71 and AMM 75 mobility models, and
- c. the Swedish system.

5. Correlative Systems

In this system the performance of a vehicle is specified or measured by comparison with that of a standard vehicle in the designated terrain. As a general rule qualitative terms are used to define both vehicle and terrain and a typical specification might state: "The vehicle shall have a performance in deep snow equal to that of ---- (the standard vehicle)." On the surface this seems a relatively simple definition and one which can be easily verified. A patch of soft snow is found and the candidate vehicle together with the standard are tested and a suitable parameter is measured to define performance; this could be speed, draw bar pull, manoeuvrability etc. Similar tests may be conducted in other terrain types and a performance matrix established. Problems arise when the performance required is "better than that of ----" and in this case the selection and measurement of performance parameters becomes critical.

6. The system has the major disadvantage of failing to provide designers with specific guidance. To create and validate their concepts they must attempt to identify the characteristics which

control the performance of the standard vehicle and try to equal or better these in their concept. The evaluation of the concept relies on the same technique but probably involves different people who weigh the characteristics of the vehicles differently. The process thus becomes dominated by opinion which may persist through the prototype performance test.

7. There is very little usable feed back from test and evaluation because the reasons for the performance of the standard vehicle were probably not clear in the first case and the reasons for success or failure of the test vehicle are even less apparent.
8. As there can be no validation of the concept until the prototype is built and tested the prudent developer tends to follow the form of the standard vehicle particularly as vehicle form appears to have a significant effect on performance. Improvements therefore are restricted to component design and advance in state of art tends to be slow.
9. AMC 71, AMI 75 MOBILITY MODELS (2)

These are analytical models developed in the United States for the computerized evaluation of the mobility of ground mobility systems. AMI 75 is the successor system to AMC 71 and was scheduled for release in the fall of 1975. The definition of mobility used in the models is that of speed made good between two points in a specified terrain and the output is expressed in miles per hours with the "no gc" condition expressed as zero speed.

10. In the application of the models an operational scenario is created and the mission of the vehicle defined. The AMM 75 model provides for either the traverse of a predetermined path through the selected area or the automatic selection of the best path between two points in the area. In either case the procedure and inputs into the program are the same.
11. The area which the vehicle must traverse is divided into patches, linear features (eg streams) and road segments each of which is assumed to possess uniform mobility influencing characteristics along its length. The properties of each patch, including surface composition and geometry, vegetation and the physical nature of obstacles are defined by 22 numerical parameters. Additional numerical definition of linear obstacles and road segments is required to complete the terrain input to the model. (4)
12. The model requires that the vehicle be defined in great detail in terms of its inertial and mechanical characteristics. Provision is also made for factors describing the drivers tolerance and acuity.
13. From these inputs the speed at which the vehicle will cross each patch or linear feature is computed and the average speed along the path through the area is arrived at.
14. AMM 75 is acknowledged by its designers to be incomplete in some respects and imperfect in most but is claimed to be a tool which, when used with an appreciation of its limitations, will provide a

means of generating quantitative engineering information for use by engineers and users in establishing mobility criteria, determining and comparing various concepts in specific terrains and the influence of specific design changes on cross country performance.

15. No information is available on validation of AMM 75. Validation trials on AMC 71 indicated an overall prediction accuracy of 69.9% on traverse tests conducted at five sites using a mix of tracked and wheeled vehicles. Analysis of the results was claimed to show that accuracy would increase to at least 85% if corrections to surface roughness and manoeuvre relations were made (3).
16. The prediction accuracy obtained varied widely between the various computer modules. For example the 'NO GO' condition for an M113A1 climbing a sand slope was predicted at 69% while the observed limit during validation tests was 33%. Similarly predicted speeds in the vegetation submodel were generally 1.5 to 2.0 times faster than the measured speeds. In other modules however, reasonable agreement between predicted and measured values was obtained.
17. Swedish Terrain Classification and Mobility Model (5)

The Swedish terrain classification system has its origins in the need of the Swedish Forestry Service for uniform descriptions of terrain for the purposes of:

- a. planning,
- b. operations control,
- c. machine appraisal, and
- d. work studies.

18. The terrain classification system identifies as its three primary elements:

- a. ground conditions, including soil characteristics, wetness and obstacle density,
- b. ground roughness, and
- c. slope.

19. These three primary elements in any patch are assigned ratings from 1 to 5 in ascending order of difficulty. Conditions judged as lying between those defined by two sequential numbers may be identified in double digits by including both numbers.

20. Swedish Vehicle Mobility Classification

The vehicle mobility classification system derives from the terrain classification system and describes the performance of a vehicle numerically in terms of its ability over ground conditions described by the terrain classification system.

21. Mobility Modelling

The Swedish Army mobility model is a simulation model designed to simulate the movements of arbitrary vehicles or arbitrary columns of vehicles in arbitrary terrain environments. It provides a means of selecting the mix of vehicles for different units in various operational zones.

22. The input to the model is derived from a scenario depicting a typical move over a specified route by a unit equipped with specified vehicles. The output provides a representation of the progress of the march at any time and a statistical presentation of the march on its completion.

23. Discussion

Of the three systems considered AMM 75 appears at first sight to offer a system of terrain description and mobility prediction which will best meet the needs of the vehicle development and concept evaluation process. The Swedish system predicts the overall mobility of vehicles and groups of vehicles based upon the observed mobility characteristics of individual vehicles in specific ground conditions and does not lend itself to the solution of design problems.

24. The complete AMM 75 model is very complex. It is, however modular in nature and the majority of the modules have a "stand alone" capability. The modules employ inputs of terrain characteristics which may be measured by means of techniques which, if not universally accepted are at least well known.

25. The accuracy of the model in predicting vehicle mobility has not been validated however, and the results of the validation trials of AMC 71 are not particularly encouraging. The model in its present form accomodates input for only shallow snow cover and appears to have only limited capacity for certain classes of

obstacles and some classifications of miskeg.

26. While the 'speed made good' definition of mobility is an excellent one for general purposes one of the principal aims of development activity is reduction of the size of the "NO GO" areas. Interest centres therefore on the near zero speed condition and the assumption is made that speed will be higher in less difficult conditions. This assumption is not always correct but it is easier, as a general rule, to identify vehicle/terrain parameters likely to limit vehicle speed in less difficult conditions and to estimate their effect than it is to predict the location of the GO - NO GO boundary condition.
27. This leads to the notion that, in developing concepts, the design point of the equipment should lie at the limit of performance required in various terrain conditions. If this notion is adopted it leads to the requirement for a mobility prediction system which is accurate and responsive over a relatively narrow band of terrain conditions. It seems likely that much of the AMM 75 model would be redundant in this limiting condition and the accuracy and sensitivity of the applicable portions may not be adequate for the task.
28. As has been noted earlier, the correlative system does not provide sufficiently specific criteria to allow the development and evaluation of vehicle concepts. Provided the standard vehicle is carefully chosen, however, the system is capable of detecting the conditions which tend to restrict or inhibit the mobility of the

vehicles it typifies. It thus may be used to locate limiting or near limiting conditions in appropriate terrain categories and these may be measured and defined in parameters suitable for input into AMM 75 or other analytical models.

29. The standard vehicle may thus be used to generate data to validate or modify existing models such as AMM 75 or to develop new models so that the conditions at the limit of mobility may be evaluated in detail. Extensions of the modelling technique to provide diagnostic output may be supported by field or laboratory test of the standard vehicle.

30. The models thus developed may be used to determine the potential of vehicle concepts with some degree of assurance that they have reasonable accuracy when applied in the narrow band of conditions for which they were designed.

31. It is possible that more than one standard vehicle will be required to cover the range required and the selection of the vehicle(s) must be made with great care. They should possess characteristics as close as possible to those of the vehicles to be developed or evaluated. The use of vehicle rigs or subscale modelling appears to offer possibilities.

SECTION 5

THE POTENTIAL OF CANADIAN INDUSTRY

1. The Industry

The great majority of the motor vehicles used in Canada are produced within the country. The automotive industry is U.S. controlled and subsidiary companies produce equipment to US designs. As most of the population of Canada lives within 50 miles of the US border and most of the vehicles are operated within this area, the performance obtained is close to that obtained in the Northern U.S. and this appears to be considered satisfactory. As the scene of operations is moved northwards this becomes less true but adequate performance seems to be obtained by a combination of personal ingenuity and rapid obsolescence. There has been no pressure since the Second World War for the manufacturers to develop a Canadian technology base and they now rely exclusively on the U.S.: they have virtually zero capability of undertaking independent research and development.

2. The need to conduct transport operations in the North, principally by oil companies, coupled with the problems of winter transportation in rural Quebec led to the development of an off road vehicle industry in Canada. There are three major manufacturers and a number of smaller companies many of whom receive government assistance in one form or another. The products range from small snowmobiles to large tracked vehicles capable of hauling gross train weights in the order of 200 tons.

3. The existence of a wide range of problems involved in moving over the wide range of terrain types which exist in the North has attracted the interest of researchers in universities and there has been some activity in the area of terrain-vehicle interaction. In some instances relationships have developed between universities and manufacturers leading to co-operation in research and development of vehicle sub systems. There are in addition a few consulting engineering organizations which specialize in northern transportation. These are principally operator oriented and provide a service to equipment users.
4. The large transport operators providing transportation of personnel and materials in the North influence the vehicle manufacturers indirectly by purchasing or not purchasing their equipment. They appear to have had little direct influence on design in whole or detail since the vehicles settled into their present form in the 1950's.

5. Research and Development Potential

The process of research, development and production of equipment requires the participation of research agencies and industry. The DREO intra and extra mural programs together with other research activity known to be in progress indicates the existence of a limited basic research capability in the field. There is little indication, however, of even a limited development capability in industry outside of certain restricted fields.

6. Before a program of research and development of technology in the field of northern mobility can be undertaken the potential of industry must be determined and plans made to exploit or further develop this potential during the program.
7. The type of program proposed should be of interest and value to both individual companies and the industry as a whole and its nature should be explained when conducting investigations of industrial potential.
8. Criteria for Evaluations

The following criteria should be evaluated during the investigation of the potential of the off road vehicle industry:

- a. interest in participating in equipment and/or technology development, (consider past performance)
- b. areas of particular expertise or interest, (as claimed by company)
- c. experience in field for which expertise is claimed or interest expressed (as a corporate organization),
- d. qualifications of individual staff members, including academic qualifications, experience, and demonstrated expertise in field of interest,
- e. access to, relationship with and use made of research agencies such as universities and/or consultants, (These agencies should be assessed separately)
- f. participation of corporate body or individuals in professional or technical associations, (distinguish between

passive membership and active participation, papers presented to ISTVS or SAE etc may be a suitable measure),

- g. extent of corporate data base (if any) and degree of access to or utilization of outside data banks eg. CANOLE, ORBIT etc,
- h. interest in participating in program which would provide access to a data base covering the technology of off road vehicle design, (the measurement of interest must be the degree of effort company is prepared to exert before expecting remuneration),
- i. current research/development program,
- j. expenditure on research/development as percentage of gross revenue past five years,
- k. possession of or access to laboratory facilities for support of research/development activities and extent of usage, (describe nature of facilities),
- l. possession of or access to vehicle test facilities and extent of usage, (describe nature of facilities),
- m. test and evaluation techniques for new vehicle systems and sub systems, and
- n. possession of or access to physical plant for the development of components or the construction of prototype vehicles.

9. Conduct of the Evaluation

It is suggested that the investigation and evaluation process should be conducted by a team drawn from the Departments of National Defence, Industry Trade and Commerce and Supply and Services.

SECTION 6

THE DATA BANK

1. Equipment development is the process of applying the known state of art to the creation of an equipment designed to fill a specific requirement. Research fills gaps in state of art knowledge and seeks to extend its frontiers. The two processes overlap in that development frequently expands state of art knowledge and applied research may result in new equipment.
2. In undertaking either research or development it is necessary at the outset that a knowledge of the applicable state of art exists or is readily available. It is fallacious to assume that state of art knowledge is a common possession of engineers in industry or government service. A few individuals in both areas, as a result of many years of experience, have acquired an extensive background in certain areas but they are limited in numbers and scope and frequently confuse state of art with folklore.
3. The discontinuous nature of development effort in Canada has inhibited the growth of a store of state of art data in either individuals or organizations. As a result development activity tends to start from a very low state of art data base and a disproportionate amount of the funds available is spent in educating the staff of the contractor in the art it is expected to apply.

4. If the development of technology and/or equipment for mobility in the Canadian environment is to be undertaken it is essential that the current state of art be defined and that potential users be advised of its nature, extent and applicability.
5. Technical libraries already contain much of the data required to form a state of art data base in this field and computerized data banks have increased its accessibility and reduced search times. A limited survey of the Land Technical Reference Library and the data bases available to the DSIS automated information system revealed little overlap but many apparent gaps in information coverage. For example a search for information on off road articulated vehicles produced 6 relevant references out of a total of 40 titles listed. The coverage of the references was not extensive and a further 5 or 6 (minimum) applicable references which are known to exist were not exposed.
6. The DSIS presentation is good and the system is responsive to the users needs; considerable skill or experience is necessary however to extract the maximum from the system. It appears that the data bases it uses would need considerable augmentation if it is to meet the requirements of a state of art data base in the mobility field.
7. There is a number of ways in which an existing data base may be augmented or a new base created. The essential steps appear to be:

- a. review the content of all libraries and data bases to which access can be gained and identify pertinent data;
- b. examine most accessible bank (eg DSIS) for completeness and arrange to augment bases as necessary;
- c. determine areas where incomplete or inadequate data is available,
- d. advise potential users of the existence and content of the data base, and
- e. arrange for automatic addition of applicable new material to data base.

8. It is to be expected that significant gaps will be found in the coverage available from the reference sources. The filling of such gaps as well as the extension of the coverage of the data base forms a principal objective of the technology development program.

9. The collection and cataloguing of applicable data is a somewhat sterile process and the issue of a catalogue is not, in itself, likely to be a sufficient stimulus to the potential user. There is a need to issue a state of art review which examines available data, reviews its applicability and in many cases its credibility, and establishes the connection between associated work. In areas where gaps exist, either in state of art knowledge or in the published literature, the review must, as far as practicable, provide authoritative coverage.

10. The structure of the review should follow the structure of the data base and it should be written as the base is established. Once published it should be reviewed periodically (say annually) and updated. The proposed chapter headings and content for the review (and hence content of the data base) are:

- a. The Philosophy of Research and Development - reasons for R and D, categories of approach, evolutionary and revolutionary techniques, theory of limited advance, law of diminishing returns.
- b. Environmental and Terrain Factors Influencing Design - the Canadian environment, general geographic areas, the geology of the north, geomorphic factors, soil condition, muskeg, snow conditions, the influence of vegetation, tender soils, rivers and streams, ice conditions inland and coastal.
- c. Terrain Classification and Mobility Prediction - measuring techniques for defining soil characteristics and other terrain parameters, analytical models for predicting concept mobility, the influence of varying vehicle parameters, capabilities and limitations of systems, sub scale models.
- d. Terrain Vehicle Interaction - tractive effort and motion resistance, floatation in weak soils, influence of soil conditions and characteristics, obstacle classification, water mobility, entry and exit problems, classic concepts of track and wheel, influence of grouser shape and size.
- e. Vehicle Morphology - the development of vehicle forms, historical influences, analogies in nature, limiting tech-

nological factors, typical vehicle forms, the influence of vehicle size, possible areas of development.

- f. General Mechanical Design - space and weight requirements for major components, vehicle layout, man machine relationship.
- g. Running Gear - tracks vs wheels, unconventional wheels, hybrid arrangements, walking machines, auxiliary support and propulsion mechanisms.
- h. Air Cushions - skirt design, influence of aspect ratio, A/C vehicle capabilities and limitations, hybrid forms, influence of vehicle size, future applications.
- i. Tracks - track design, girder tracks, flexible tracks, band tracks, pinned tracks, rubber bushes, strength considerations, grouser forms, typical construction, materials, limits to use of elastometers, environmental impact, sprocket design, influence of pitch on vibration, sprocket fouling, front vs rear sprockets, track tension, track guiding, roadwheel design, roadwheel spacing.
- j. Suspension Design - suspension arrangement, independent suspensions, compound suspensions, walking beams, load criteria, wheel travel, oscillation damping, types of dampers, active suspension systems, influence of vehicle form, permissible levels of shock, spring rates, limiting terrain characteristics, suspension as a mobility limiting factor.
- k. The Engine Compartment - selection of engines, power requirements, load factors, fuel consumption, specific bulk, specific weight, cooling requirements, parasitic power losses, cooling system design, fan types and applications, air flow in the compartment, induction requirements, exhaust require-

ments, typical engine compartment arrangements, auxiliary drives.

- l. The Drive Line - transmission selection, the influence of rolling resistance, transmission types, manual transmissions, automatic stepped transmission, torque converters, hydrostatic transmission, power splitting techniques, electric drive, typical transmission applications.
- m. Steering Systems - Ackerman steer, wagon steer, articulated steering, geared steering, track warp, the mechanics of tracked vehicle steering, skid steering of wheeled vehicles
- n. The Articulated Vehicle - wheeled, tracked, modes of articulation, articulation restraint, steering theory, steering methods and mechanisms.
- o. The Electrical System - calculation of power requirements - power consuming devices, the function of the battery, battery types and characteristics, charging systems, suppression requirements and techniques.
- p. Design for Low Temperatures - the starting problem, fuels and lubricants, engine characteristics, battery types and characteristics, stand-by heaters, flash heaters, flame primers, starting fluids and primer systems, selection of materials, elastometers, plastics, metals, practical limits for operation with and without starting aids, practical (economic) limit of vehicle operation.
- q. Design of Vehicle Structures - application of materials, avoidance of panel drum, high/low modulus interfacing, weight/cost relationships; framed structures, monocoques, body

mounts, insulation.

- x. Human Engineering - seating, vision, design and positioning of controls, instrument panels, lighting, heating, cooling, vibration and shock limits, effects of very low temperatures.
- s. Vibrations in Vehicles - suspension/terrain induced, wheel or track to ground induced, drive line induced, analysis of vibrations, technique of vibration control.
- t. Design for Maintenance - requirements of military system, reduction of maintenance requirements, increase of servicing intervals, accessibility, power pack concepts, hardware standardization, mtbf prediction, auto analysis systems, self analysis systems, life cycle costing, maintenance at low temperatures.
- u. Design for Value - cost engineering, value engineering, influence of life cycle costing on selection of components, cost-value of weight reduction, influence of cost on environmental limits.
- v. Testing and Evaluation - the evaluation of design concepts, matrix evaluation techniques, types of tests, test facility design, effect of sample size on validity of results, evaluation of test results.

SECTION 7

A PROGRAM TO DEVELOP A TECHNOLOGY BASE

1. Assumption In developing this program it has been assumed that the requirements set out for the M91V 80 rifle - the type of equipment likely to be required by the Canadian Forces for the 1980-1990 period. A vehicle meeting these requirements is likely to have a gross weight of 15,000 lb or less and to possess an optimum combination of mobility characteristics in the area extending from 200 miles south of the treeline northwards to the limit of Canadian sovereignty.
2. A preliminary survey of the accessible data banks during the formulation of the requirements for the data base proposed in Section 6 revealed many areas where current state of art information is either inadequate or of dubious applicability to the type of equipment likely to be required. There is a need, therefore, to generate state of art data in many fields to augment the proposed data base. A program of work to meet this requirement may be defined.
3. Proposed Program The first step in implementing the program should be the establishment of a data base representing the current relevant state of art following the procedure set out in Section 6. This preliminary base will be incomplete in some areas and contain material of marginal relevance in others. The accompanying "State of Art Review" should define these areas and indicate the work required to bring the base to an acceptable level.

4. The program of further work which is set out in this section anticipates the findings of the "State of Art Review" and will probably require revision as more detailed information becomes available. It is considered that the revisions required are more likely to take the form of additions to the proposed program than deletions from it.
5. In the interest of being as specific as possible within the scope of the study the program of work following the compilation of the data base has been divided into eleven projects, nine of which are defined in Projects 1 to 9 annexed to this section. The background to each project is described and the aim is defined; in most cases a method of achieving the aim is proposed. The nine projects are described briefly below:

- a. Project No 1 Terrain Classification and Vehicle Mobility

Prediction This project follows the discussion in Section 3 of this study and seeks the design of analytical models capable of predicting the performance limit of concepts or vehicles in specific Canadian environments. It introduces the concept of a reference vehicle and proposes a standard form of mobility specification.

- b. Project No 2 Development of a Concept/Vehicle Evaluation

System This proposes the development of a computer supported matrix evaluation system for evaluating candidate equipments against requirements.

- c. Project No 3 The Morphology of Vehicles for the Canadian Environment This project postulates the thesis that significant advance in mobility is more likely to be realized from improvements in vehicle form than from development of subsystems and proposes an investigation of the effect of form on mobility to establish an optimum form.
- d. Project No 4 Articulated Vehicles The probable influence of articulation mode and articulation restraint on vehicle mobility is pointed out and an investigation of the influence of the coupling on vehicle design is proposed.
- e. Project No 5 Hybrid Vehicles A general investigation of the potential of hybrid vehicles is proposed.
- f. Project No 6 Suspension Systems It is suggested that the requirements for the suspension system of an articulated vehicle are different from those of a rigid vehicle and that simpler, cheaper systems may be feasible. It is proposed that the requirements be determined and illustrated by practical designs.
- g. Project No 7 High Frequency Vibrations in Vehicles The need to reduce high frequency vibrations in vehicles, particularly tracked vehicles is pointed out. This must be done during the design phase. It is proposed to investigate the causes and to provide design criteria for noise reduction.
- h. Project No 8 Vehicle Terrain Interaction This project covers a broad field and could probably be divided into several related sub projects. It proposes investigation into many

aspects of vehicle terrain contact and suggests that the mechanics of an improved contact should be established first followed by detail design of grousers etc. It proposes as a related study the establishment of track strength criteria.

j. Project No 9 Test and Evaluation Facilities The adoption of analytical mobility prediction and concept/vehicle evaluation techniques requires the creation of controlled or standard test environments for validation of results. The project proposes that certain specific facilities be provided.

o. Two further areas of research and development are required. In each case there is already a considerable state of art which requires detailed study before the projects can be formulated in detail. These are:

a. Project No 10 Design for Low Temperatures

Probable areas for development are:

- i) the improvement of battery design,
- ii) the improvement of battery environment by the use of heated insulated battery boxes and use of heat sinks,
- iii) the development of criteria for the design and application of starting aids,
- iv) the problems of interfacing newer structural materials (eg. F.R.P.) with rigid components in the embrittling environment produced by extreme cold and with the increased shock and vibration which accompanies vehicle operation in these temperatures.

- v) the practical economic lower limit for temperature of operation.

b. Project No 11 Transmissions and Steering The thrust here is once again in the direction of articulated vehicle. It is doubtful that a case can be made for the development of transmissions, however, there is much room for the study of application of commercially available components. Probable fields of development are:

- i) the application of electric or hydrostatic transmissions.
- ii) automatic engagement of part time hydrostatic drive associated with track tension variation in one unit,
- iii) the steering of articulated vehicles, including revision of steering kinematics, the investigation of the forces involved and various solutions to the steering problem.

PROJECT NO 1

TERRAIN CLASSIFICATION AND VEHICLE MOBILITY PREDICTION

BACKGROUND

1. The development of vehicles for operation in difficult terrain requires that the nature of the terrain be defined, and in particular that the characteristics of terrain features which limit vehicle performance be described in a precise fashion. This requirement has long been recognised and work has been carried out by Parry and others in Canada on techniques for classifying terrain primarily in order to provide mobility maps. Extensive work carried out at the Waterways Experimental Station and elsewhere in the United States resulted in the development of analytical models by means of which the mobility of a vehicle within a prescribed area may be predicted in terms of speed made good between two points.
2. In designing a vehicle it is necessary to select points on the desired performance profile which will serve as design points. These design points normally reflect the performance required of the vehicle under limiting environmental conditions. The success or failure of the design depends largely upon the skill of individuals in selecting the design point and estimating the performance of candidate systems and subsystems in the environment thus defined.
3. The evaluation of the design is conducted by constructing a prototype and evaluating under conditions judged as representing the desired

limit (not necessarily by the designer). Novel designs are appraised by the corporate eye of the potential user and his advisers and if judged worthy are subjected to physical evaluation. Opinion reigns supreme in this process, argument resolves differences of opinion, and issues are frequently settled by agreement on semantics which may have little relevance to the problem. The process is imprecise and costly.

4. The AMC 71 and AMM 75 mobility models developed in the United States are claimed to provide a tool by means of which, among other things, a design agency may predict the mobility of a vehicle in a given set of conditions and assess the effect of varying certain design parameters. The validity of these claims, particularly in the limiting cases, is uncertain; validation trials with AMC 71 do not inspire confidence.

#### AMM

5. To define an analytical model which will allow the accurate prediction of the mobility of conceptual vehicle designs in specified limiting conditions.

#### METHOD

6. The following conditions will be considered:
  - a. soft ground,
  - b. muskeg,
  - c. deep snow,

LIST OF REFERENCES

1. Request for proposal, medium marginal terrain vehicle (1980)  
dated July 9, 1975
2. The US Army Mobility Model (AMM 75) Jurkat et al Proceedings -  
5th International Conference, International Society for Terrain  
Vehicle Systems
3. Validation of the AMC 71 Mobility Model BG Schreiner and WE Will-  
oughby. Proceedings 5th International Conference Society for  
Terrain Vehicle Systems.
4. Terrain Modeling to Support Mobility Evaluation, AA Rula and CJ  
Nuttall JR. Proceedings of 5th International Conference - Inter-  
national Society for Terrain Vehicle Systems
5. Vehicle Mobility Modelling and Terrain, Correspondence Group visit  
to Sweden May 1976 - Raymond N Young McGill University, Montreal

- d. shallow snow,
- e. rough ground,
- f. linear obstacles,
- g. slopes in conjunction with soil/snow conditions,
- h. roads,
- i. vegetation.

7. The validity of the philosophy of design for limiting conditions which assumes that if a vehicle can traverse a certain limiting condition it will have satisfactory performance in less stringent conditions, will be determined.
8. For each of the terrain types listed the limiting condition shall be identified: this is the extreme condition which the projected vehicle may reasonably be expected to traverse and lies next to the NO GO condition. Identification should be carried out by physical survey conducted by representatives of the user agency assisted by advisers. A reference vehicle as close as possible in size and performance to that desired should be used to assist in identification of limiting conditions and its performance recorded. The terrain parameters likely to be required in the construction of an analytical model should be recorded at both the desired limiting conditions and the limit of the reference vehicle. Initially the expression of the parameters should be compatible with AMM 75, however additional measurements using other techniques should be taken. (See Project No 9.)

9. A survey of mobility prediction techniques should be carried out and those considered most likely to fit the requirement for accurate prediction at or approaching limiting conditions selected and evaluated against the field results.
10. The applicability of AMM 75 should be appraised and the possibility of adapting the relevant modules should be investigated. If this proves impracticable appropriate models should be designed.
11. Validation of the analytical models by field and laboratory tests should be conducted.

OUTPUT

12. The models are required to provide output which will allow the appraisal of wheeled and tracked, single unit and multi unit vehicles against a specification similar to that in Annex A to this project.

COMMENT

14. The method set out above is intended as a basis for discussion between the technical director of the project and the implementing agency. It indicates in general terms the steps that appear necessary to reach the desired results although not necessarily in the order stated.
15. At first sight it appears that the intention is to duplicate the work done in the United States on AMM 75. This is not so. The

intent is to provide a tool or series of tools which will allow the prediction of the ability of a vehicle concept to cross a clearly identified terrain type in cases where both the vehicle size and terrain characteristic occupy a relatively small band of the overall spectrum.

16. If necessary separate models may be provided for each terrain type and for each vehicle form, the desire to combine the whole process into one elegant solution should be resisted.
17. Close control of the project must be maintained to avoid a mathematical orgy leading to a result which lacks creditability because nobody understands it.
18. There may be wide difference in the ratio of significance of the information provided and the effort required to create an analytical model to produce it. This factor requires close attention at the start and effort should be directed to areas where it is most likely to produce a useful result reasonably quickly. This would appear to favour early work on prediction of soft ground performance. The complexity of snow cover will undoubtedly create problems and initially it may be necessary to generalize by assuming that a concept having good performance over very soft soil will probably perform well over deep snow. The rough ground characteristics of a vehicle need very detailed input on the vehicles physical character and much of this is not available until a great deal of design work has been done. It may be necessary at the concept

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stage to use the corporate eyeball to appraise the rough ground characteristics using whatever tool that can be developed as a design aid.

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ANNEX A TO PROJECT NO 1

TYPICAL EXPRESSION OF PERFORMANCE REQUIREMENTS

NOTES

1. This document sets out a typical statement of the performance requirements for a vehicle for use in northern terrain. The definition of soil and obstacle parameters must be compatible with the requirements of the mobility prediction system; those used in this specimen are for illustrative purposes only.
2. In specifying the performance over weak soils the limiting case has been used. It will probably be found desirable to include also a requirement to achieve stipulated speeds over sub limiting soil conditions.
3. If a reference or standard vehicle is used in establishing the requirements its performance should be shown either here or in a similar accompanying document.

REQUIREMENTS

4. Weak Soils The vehicle shall be capable of making a single pass

over level terrain having the following characteristics:

- a. (UCS type, cohesive) soil having RCI (or RI) of ----.
- b. (UCS type, frictional) soil having RCI (or RI) of ----.
- c. ---- (Type) Muskeg.
- d. ---- ft of snow having density of ----, -% water content and ---- (other parameters such as C,  $\phi$  etc if applicable).

5. Slope Performance The vehicle shall be able to:

- a. climb a maximum slope of 60% (say) at - mph.
- b. climb a slope of - at - mph on (UCS type, cohesive) soil having RCI (or RI) of -.
- c. climb a slope of - at - mph on (UCS type, frictional) soil having RCI or RI of -.
- d. climb a slope of - at - mph on - ft of deep snow having density of -, -% water content and ---- (other applicable characteristics).
- e. traverse and manoeuvre on a maximum side slope of 40% (say).
- f. traverse and manoeuvre on side slopes of -% on (soils, deep snow having characteristics ---- described as above).

6. Obstacle Performance The vehicle shall be capable of:

- a. traversing a single obstacle having a height of - and width of -.
- b. traversing repeated obstacles having a height of - and width of - at - spacing at - mph without exceeding - g measured at the drivers seat.
- c. crossing sharp edged ditches having a width of -.

7. Rough Ground The vehicle shall be capable of traversing rough ground having an RMS roughness of - inches at - mph without exceeding - watts of absorbed power at crew/driver seats.
8. Manoeuvrability The vehicle shall be able to traverse a tree covered area having trunks of - diameter at a spacing of - at - mph assuming adequate visibility.
9. Stream Crossing The vehicle shall be able to cross streams having the following characteristics:
  - Depth - ft
  - Width - ft
  - Velocity - fps
  - Entry bank slope - deg
  - Exit bank slope - deg
  - Vertical height of bank above water - ft
10. Road Performance The vehicle shall have a maximum speed of - mph on smooth level road and a speed of - mph on a slope of -%.
11. Mission Capability The vehicle shall be capable of completing the mission set out in the accompanying mission profile at an average speed of not less than - mph with a fuel consumption not exceeding - mpg.

PROJECT NO 2

DEVELOPMENT OF CONCEPT/VEHICLE EVALUATION SYSTEM

BACKGROUND

1. The process of selection of a concept for development or a vehicle for acquisition requires that a system exist for comparison of the characteristics of candidate concepts or equipments with each other and with a set of standards which represents the requirement. For valid comparison the characteristics must be measured and expressed in a standard fashion.
2. Not all characteristics have equal weight in influencing the suitability of a candidate. There are frequently certain areas in which the failure to meet a specified level of performance disqualifies the candidate from further consideration. The weight of the characteristics will vary between equipments intended for different end use and even between the different roles of a single equipment.
3. Some of the information required will be produced by the mobility prediction system, other will be based on contractors estimates and some will result from measurements taken during tests or trials.

AIM

4. To develop a standard method of evaluating concepts or vehicles against specifications and requirements.

METHOD

(NOTE: There are a number of possible approaches to the problem; one is suggested below to illustrate features which are likely to be common to all systems.)

5. Determine characteristics which will influence the selection process and define a standard means of expression and measurement.
6. Establish method of assigning weighting factors and likely ranges of such factors. The means of defining mandatory requirements should be decided.
7. Design system for estimating concept/vehicle performance characteristics under conditions imposed by typical mission profiles.
8. Design module matrices for comparison of characteristics or groups of related characteristics eg. payload, speed and fuel consumption.
9. Design master matrix with computer program support to evaluate (weighted) output from module matrices and provide ranking of candidates.

COMMENT

10. The evaluation technique would obviously form an appropriate study for operational researchers.

11. The development of an evaluation system will not be easy. The initial target is to provide a system which has more credibility than the corporate eyeball technique and to improve from that base system. Developers must be prepared to compromise and avoid endless search for the perfect system.
12. The system must be credible to the people who are going to use it, all steps should be visible and coherent. Provision for validation of modules should be made.
13. Analytical models produced to support the system must allow easy modification to accommodate developing knowledge and changing circumstances.

PROJECT NO 3

THE MORPHOLOGY OF VEHICLES FOR THE CANADIAN ENVIRONMENT

BACKGROUND

1. It is generally accepted that, since the introduction of the crawler tractor, there has been very little advance in field of off road mobility. This applies in particular to the development of capability to operate over weak soils. It is probable that the most significant advance in the field of small vehicles occurred in the early 1950's when the Canadian Army introduced the concept of small articulated track layers for employment in tree line snow conditions. The concept of tandem track arrangement involved a radical change in vehicle form and produced a dramatic increase in performance of small vehicles.
2. At the time of the original studies and trials it was apparent that several forms of tandem track arrangement were possible, however full investigation of all alternatives was not carried out. There is evidence that the currently conventional articulated vehicle arrangement provides little enhancement of performance with large vehicles and it appears therefore that, in view of its higher cost it becomes less cost effective than the single track steered vehicle. The location of the cross over point obviously varies with soil conditions and probably with the arrangement and coupling of the tandem tracks. It should be noted that there appears to be a second cross over with very large vehicles: this probably lies outside the scope of this project.

3. The form and size of vehicles changes when wheels are used instead of tracks and while it appears unlikely that wheeled vehicles will provide a comparable performance to tracks within the same physical dimensional envelope there are probably cost advantages to be gained by their use. Rolligon and terra tire concepts are worthy of study within the context of small vehicles of novel form.
4. Vehicles are immobilised in weak soils by increased motion resistance associated with sinkage. The motion resistance has a component which derives from the drag of the vehicle belly and which varies in magnitude with a number of vehicle design factors. The influence of belly form and design for minimum drag within a concept designed to derive a degree of support from this element in compressible soils has been the subject of limited investigation.
5. Bellyless vehicles, using either wheels or tracks have been shown to approach the ideal form for deriving floatation and traction from weak soils. Using conventional running gear componentry however they tend to have high centres of gravity and are narrower than equivalent belly type vehicles having similar physical characteristics. These two factors contribute to instability particularly on soils or snows of varying strength and on certain hard ground obstacles. There is obviously an optimum compromise for various classes of vehicle and this appears worthy of investigation.
6. The unwritten law of identity of unit size and form in two unit articulated vehicles which is followed by many designers does not

appear well founded. There appears to be scope for track-wheel or wheel-track arrangements or for belly-bellyless combinations where these can be shown to offer advantages. It appears highly probable that, for example, the optimum size and form of a front unit which carries the crew and propulsion mechanism is different from that of a rear unit which carries the payload. There is some evidence that the units of a two unit train make unequal contributions to the overall tractive effort and this factor should be considered in determining the overall vehicle form.

7. Air cushion vehicles and partial air cushion support of conventional vehicles appears to have little application in vehicles of the size and type being considered however the technology should be examined.

AIR:

8. To examine the effect of vehicle form on mobility in the Canadian Arctic and Sub Arctic and establish optimum forms for various sizes up to 15,000 lb g.v.w.

METHOD

9. The following factors shall be considered:
  - a. the nature and frequency of occurrence of mobility limiting terrain features (Project 1),
  - b. the performance of the various forms studied in each of the limiting terrain features,
  - c. the initial cost, life time cost and operating cost of the various forms,

d. the utility of the various forms to fill the roles outlined in the --- applicable operational requirements.

10. The use of wheeled and tracked vehicles of single or multi unit configuration should be studied.
11. The use of unconventional means of support and propulsion should be examined alone and in conjunction with more conventional techniques.
12. Mobility enhancement techniques which can be applied to conventional and unconventional vehicles should be investigated.
13. Optimum vehicle forms for various sizes and areas of operation should be proposed.

COMMENT

14. This project is closely associated with Projects 4 and 5.
15. As there is a relationship between vehicle form and vehicle size it seems desirable initially to place emphasis on a range of sizes which reflects likely operational requirements. The range up to 15,000 lb gvw is suggested.

PROJECT NO 4

ARTICULATED VEHICLES

BACKGROUND

1. The concept of the articulated tracked vehicle has existed since the early 20th century. The development of practical steering systems for rigid vehicles during the First World War inhibited development of the articulated form and there was little, if any, practical application of the principle until the early 1950's.
2. While it has been shown that the application of the articulation principle results in enhanced performance of small vehicles and allows the construction of practical vehicles capable of carrying very large payloads the mechanics of the coupling process has not been fully explored.
3. The original light articulated test rig used to demonstrate the principle consisted of two identical units coupled by ball joint(s) at a point on their longitudinal centre line. The joints provided freedom in roll and pitch and steering was obtained by control of yaw. This base concept has persisted and been repeated in successor vehicles.
4. There is evidence that in certain conditions the two units of a vehicle make quite different contributions to the net tractive effort of the vehicle. There is also evidence that freedom in the roll plane detracts from performance in conditions where there is

a wide local variation in soil strength. Performance in crossing certain classes of obstacle is reduced by the large space which exists between the tracks of the two units and the space between the two hulls leads to reduction of speed in water.

5. In terms of component design it is apparent that peak loads on individual running gear components in a vehicle which behaves as a single rigid unit will be different from those in one where the two units behave essentially as two small vehicles.
6. These factors and others suggest that the current method of coupling is not necessarily the best. An investigation of various coupling techniques with various degrees of constraint in the planes of articulation is required. Promising techniques may be investigated by full scale or sub-scale testing.

#### Aim

7. To investigate the influence of the coupling of the units in an articulated vehicle on vehicle design.

#### METHOD

8. The forces and moments existing between the units of a simply articulated vehicle operating under various conditions should be identified and evaluated.
9. The effects of imposing constraints on the freedom of motion in pitch and roll on the performance of a vehicle should be investigated.

10. The tractive effort produced by each unit of an articulated train under varying operating conditions should be determined and the effect of constraints observed.
11. The effect of variation in relative sizes of the units of an articulated train on vehicle performance should be investigated.
12. The requirements for the propulsive mechanism of each unit should be considered and recommendations developed on the use of wheels or tracks or a combination of both should be made.
13. The various methods of coupling the units of an articulated vehicle should be examined in the light of the above data and promising techniques should be evaluated by test.
14. The work should be prosecuted to the point that practical alternative vehicle designs are proposed.

PROJECT NO 5

HYBRID VEHICLES

BACKGROUND

1. There are many methods of support and propulsion available to the vehicle designer, each has particular virtues in certain operating environments none is of truly universal application. In attempting the combination of two or more techniques into a single vehicle the resulting hybrid generally seems to emphasize the worse features of each technique.
2. In the examination of the articulated vehicle (Project 4) the possibility of creating an operating environment in which it may be possible to a combination of wheels and tracks has been suggested.
3. Towed air cushion rafts in which the propulsive and support functions are separated have shown promise in certain types of northern operation. The extension of this principle to an integrated vehicle may hold some promise. Early work in this direction concentrated on the use of light wheeled chassis and achieved only limited success.
4. The walking machine which in its pure form seems to present considerable design problems may provide an attractive and viable mechanism in combination with other means of support and/or propulsion.

AIM

5. To examine the potential of hybrid vehicle systems.

METHOD

6. Establish operational mission profile.
7. Define the basic physical parameters of the vehicle likely to be required.
8. Review the state of art in various methods of support and propulsion. These should include wheels of various types and forms, applied traction devices, tracks, air cushions, air screws, archimedian screws, walking devices, skis, etc.
9. Establish the performance of typical vehicles employing single system support/propulsion device in the terrain defined in the operational mission profile. Terrain factors limiting performance should be identified.
10. Examine combinations of various systems of support and propulsion seeking an optimum combination of performance characteristics. The part time use of auxilliary means of support or propulsion to traverse particular classes of terrain should be considered. Air cushions, air screws, skis etc. should be considered both as primary and auxilliary systems.
11. Review the logistics implications of promising combinations and re-examine the physical parameters of practical vehicles.
12. Formulate a program to develop promising combinations.

PROJECT NO 6

SUSPENSION SYSTEMS

BACKGROUND

1. Suspension system for rigid wheeled and tracked vehicles have been extensively investigated. Research and development programs by industry and by governmental agencies have established computerized design techniques and lead to well defined design principles. The springing media for use in these suspension designs have formed the subject of similar intense study. Neither of these fields is likely to form a fruitful field of investigation in a relatively low budget program.
2. There has been little study of the requirements for the suspension for an articulated vehicle and it appears that these differ from those of a rigid vehicle.
3. The units of an articulated train interact in the pitch and roll modes of vibration. The extent and nature of this interaction may be varied by the design of the coupling mechanism and has an influence on the requirements of the suspension systems.
4. There is a possibility that the weight, cost and complexity of the suspension system can be reduced if the effect of unit interaction is determined and the data established applied to design of suspensions specifically for the articulated case.

AIM

5. To determine the requirements for suspension systems for articulated vehicles and to propose practical designs.

METHOD

6. The action the suspension system and resultant vehicle oscillation should be determined for passage over various ground forms and obstacle types either by analysis or by experiment or by a combination of experimental and analytical techniques.
7. The nature and effect of the interaction between units when the train passes over various terrain types should be determined.
8. The effect of varying suspension system parameters should be determined, particular attention should be paid to wheel movement vs effective spring rates.
9. An analysis of the suspension system requirements should be made. The need for high resilience damped systems should be examined against the capability of low resilience articulated suspension systems.
10. The requirements should be illustrated by practical designs.

PROJECT NO 7

HIGH FREQUENCY VIBRATIONS IN VEHICLES

BACKGROUND

1. High frequency vibrations usually in the form of noise are the principal factor contributing to the creation of environmental conditions within military vehicles lying at or close to the limits of human endurance. The problem exists in both wheeled and tracked vehicles although the latter normally produces the worse conditions. It is virtually impossible to eliminate vibrations once the vehicle design has become firm, therefore action must be taken at the design stage to minimize or eliminate sources of vibration.
2. There are a number of sources of vibration over which some degree of control may be exerted. They include:
  - a. engine vibration and noise,
  - b. transmission gear noise,
  - c. track to sprocket contact vibration,
  - d. vibration induced by wheel to track or ground contact.

AIM

1. To investigate the causes of vibration in military vehicles and to provide design criteria for noise reduction.

METHOD

4. The source and nature of vibrations in a typical vehicle should be analysed and methods of reducing or eliminating them studied, these should include:

- a. sprocket to track tooth engagement, design of sprocket for minimum vibration, the potential of friction drives or part friction drives, the support of the track on the sprocket.
- b. track and/or grouser pitch for optimum combination of low vibration and high traction.
- c. road wheel design for minimum vibration, use of pneumatic or semi-pneumatic tires, resilient wheels etc.
- d. the application of vibration damping mountings in all applicable areas.

5. Following the analysis and confirmation testing a series of design criteria should be formulated setting out acceptable limits of vibration from various sources and approved techniques of attaining these levels.

PROJECT NO 8  
VEHICLE TERRAIN INTERACTION

BACKGROUND

1. In spite of considerable research in this field since the Second World War there has been, with one or two notable exceptions, virtually no advance in the design of the terrain contacting elements which can be said to have resulted from research activities. Design changes which have been introduced have resulted principally from product improvement programs designed to improve durability and reliability.
2. The field appears to be attractive to researchers because it affords opportunities for analytical study of the ground contact process leading to a precise mathematical expression of the relationships existing between soil parameters, track or wheel characteristics and floatation and effective pull. Unfortunately the message contained in the extensive published research data has not got through to the "practical" engineer who either fails to understand or does not believe the message. There is also the third possibility that the research has not been relevant to his needs.
3. Whatever the reasons there seems to have been singularly little application of the products of research in this field and there seems to have been a breakdown in communication between the engineering and research communities. Any program seeking the maximum effect the effort and money expended must first close this commun-

ications gap.

4. This program is concerned with the development of a technology base and the processes of research and development must be combined to produce a demonstrable technology which may be embodied in the base. The validity and applicability of research conducted under the program must, therefore, be established by hardware or technique development.
5. There are ongoing research activities under the auspices of DREO and DRFM. The proposed work in this project is intended to complement these activities.
6. There are a number of phenomena which require further investigation to establish their effect on vehicle mobility. In general terms an understanding of cause and effect should allow the development of hardware or techniques to allow maximum benefit to be gained.

#### AIM

7. To examine the mechanics of the vehicle terrain interface and to develop an advanced technology.

#### METHOD

8. The parameter most used to indicate tracked vehicle ability over soft soils and snow is nominal ground pressure. It has been shown that the actual ground pressure exerted by a track is much more

than the nominal ground pressure under the road wheels and much less between them. The distribution of pressure varies with the size and number of wheels. It has been shown experimentally that the multipass capability of a vehicle equipped with a skid type of track support exceeded that of the same vehicle equipped with conventional wheels.

9. While the significance of the variation in ground pressure in relatively shallow soils over a hard base is readily apparent the effect in very deep soft soils and snows does not appear to have been established. The importance of this case in the Canadian environment suggests that it should be investigated further.
10. The results of the investigation, together with those of previous work should suggest optimum road wheel diameter and spacing. The modifications of these criteria required to suit variations in track stiffness should be developed.
11. The net benefit accruing to the use of skids in place of wheels should be investigated and practical design concepts formulated. The use of air supported and lubricated skids as a means of reducing abrasion should be examined.
12. It is possible to visualize practical tracks which have a greater stiffness in bend in one direction than the other in the same plane. The ground loading phenomena should be examined for practical soil types and wheel spacings to determine the effect of

increasing track stiffness. If the investigation indicates benefits from practical levels of stiffness the various means of obtaining a unidirectional increase of stiffness should be investigated.

13. The investigation of the general nature of the track to ground contacts mechanism leads naturally to the conduct of similar studies and experiments in the field of wheel to ground contact. There is scope for improving wheel or tire construction to enhance the performance of wheels in varying soil condition and these should be examined. The use of unconventional wheels such as the convolute case should be considered.
14. When the nature of the track/wheel to terrain interface is established investigation of the grouser or spud used to derive traction may be undertaken. Improved distribution of ground loading will tend to reduce damage to tender soil and careful grouser design will minimize it. The action of the grouser on entering and leaving the soil requires careful attention and the possibility of using retractable grousers should be investigated. Optimum grouser sizes, shapes and spacing for maximum effort in various soils should be developed and demonstrated with practical means for reducing the vibration generated by aggressive grousers on hard surfaces.
15. The Martin track is an example of a grouserless form of track. When applied to the M113 vehicle it developed surprisingly high tractive efforts in mud. The matrix design of the Martin track is interesting and the reasons for its performance should be analysed.

16. The tracks used on vehicles designed for use in Northern Canada have traditionally taken the belt and crosslink form. Some interesting variations on this form have been introduced by the Swedish Army. There appears to be considerable scope for improvement in the design of tracks for light vehicles and criteria for tensile and transverse bending strength should be established. The mechanical design of tracks should be investigated and advanced designs making use of advanced materials should be proposed.

17. The effect of lateral stiffness of tracks on their performance and guiding shall be examined and criteria for stiffness established. Appropriate guiding techniques for various types of tracks should be developed.

PROJECT NO 9

TEST AND EVALUATION FACILITIES

BACKGROUND

1. The system proposed for the development of criteria for the expression of mobility requirements and analytical models for the prediction of mobility is based upon the determination of practical limiting conditions involving the use of a standard vehicle.
2. During the development of the system and later during its application there is a need for continuous validation by laboratory and field testing. This process requires the establishment of a set of controlled conditions some of which may be varied to represent the various standard conditions. There is also a need for a standard vehicle (or vehicles).
3. The facilities established or identified for this purpose would also be used in the testing and evaluation of prototype or sample vehicles. To some extent they already exist either at the Land Engineering Test Establishment or in the Soil Mechanics Laboratory at McGill University. It will be necessary in some cases, however, either to adapt the existing facilities or to develop new facilities to meet the new requirements.

AIM

4. To develop the test and evaluation facilities required to support the development of a technology base for mobility in the Canadian

environment.

#### METHOD

5. The proposed technology development program will lead to the inclusion of new parameters in the specifications used to govern the development of vehicles. The assumption is made that the available test facilities meet the needs of the current specifications and this project is restricted to the provision of new facilities to meet new requirements.
6. The existing test and evaluation facilities should be reviewed in the light of the new requirements imposed by the terrain evaluation and mobility prediction system and the proposed mobility performance specification. Where necessary test facilities should be modified or new facilities provided. The facilities development program will probably involve:
  - a. the definition of a standard vehicle;
  - b. the selection of a soil characteristics measuring device compatible with the terrain evaluation and mobility prediction techniques;
  - c. the design of soil bins containing a range of probably three cohesive and two frictional soils and of sufficient size to allow testing of typical northland vehicles.Facilities for conditioning and adjusting the water content of the soils must be provided. A suitable dynamometer for measuring draw bar pull will be required; this should be of a type to allow multiple passes of the test vehicle;

- d. the identification and selection of typical limiting and sub limiting muskeg conditions,
  - e. the identification of areas in which there is a reasonable frequency of consistent near limiting snow conditions. The area should include slopes,
  - f. the design of simulated rough ground conditions based upon observed limiting conditions,
  - g. the design of manoeuvrability courses to allow testing under simulated (or actual) forest conditions, and,
  - h. the selection of water obstacles having a range of representative bank conditions.
7. The implementation of the facilities development program will involve the revision of the standard test procedures in addition to the construction of the physical plant.

SECTION 8

PROGRAM IMPLEMENTATION

1. The overall program which is proposed seeks to establish a technology base which will serve as a foundation for future activities in the field of mobility in the Canadian environment. This involves the creation of a data base, the conduct of a related state of art development program and the appraisal of the potential of Canadian industry. It is a relatively large program of closely related activities.
2. It is apparent that the first step in the implementation process must be a review of the proposed program to determine whether or not it meets the needs of the Force. The program in whole and detail is based on the concept that it is first necessary to establish a base line; subsequent activities then follow a pyramidal logic. If it is found necessary to make changes in the program before implementation it is important that the concept be recognised and a conscious effort be made to avoid building pyramids from the top down.
3. It may be desirable for administrative purposes to divide some of the proposed projects into a number of sub-projects. This is possible and practical provided the correct relationship is maintained with other related projects.
4. The detailed implementation of the project depends largely on internal DND factors, principally the availability of resources and

the organizational structure of the research and development communities. The program and most of the elements in it involve both research and development and in formulating it no conscious effort has been made to distinguish between these two functions. It is essential for success that there be no discontinuity between research and development activities and the implementation plan must ensure this.

5. The availability of resources is obviously a highly significant factor. The nature of the program is such that if prosecuted at an optimum level substantial progress towards its objectives should be made in about five years. It may be possible to shorten this slightly and it is certainly possible to extend it. In opting to extend the time period caution must be exercised to avoid a diffusion of effort on too many projects.
6. An implementation plan must provide for:
  - a. maintenance of the impetus of the program as a whole and of each element within it;
  - b. maintenance of continuity of technical logic throughout the program and
  - c. flexibility to exploit success and/or to curtail effort in areas where success seems unlikely.

#### PRIORITIES

7. On the assumption that the program is to be implemented as proposed the following orders of priority are suggested:

**Priority 1 - to be conducted simultaneously**

- a. Establishment of data base
- b. Project No 1 Terrain Classification and Performance Prediction
- c. Project No 9 Test and Evaluation Facilities
- d. Establishment of Potential of Industry

**Priority 2 - to be conducted simultaneously**

- a. Project No 3 - Vehicle Morphology
- b. Project No 8 - Vehicle Terrain Interface
- c. Project No 2 - Development of Concept/Vehicle Evaluation System

**Priority 3 - the remaining projects taken in any convenient order having due regard for a certain interdependence which exists.**

8. The priorities proposed are based on an optimum five year program. It may be necessary to change them to accommodate certain ongoing research and development activity or to provide support in a specific field of technology to the MTM 80 project.

PARAGRAPHS

9. At the outset of the study it was hoped that specific proposals on a management structure could be made. As the program developed, however it became apparent that it was a relatively large undertaking which would require the co-operation of a number of DND agencies whose relationships with and responsiveness to the OPI were not immediately apparent. It is proposed therefore to suggest

criteria which should be applied in formulating the management plan without being specific as to the nature of the plan itself.

10. The management plan must meet the conditions set out for the implementation plan in para 6 above. This requires that:

- a. the program be funded at an adequate level over an initial five year period,
- b. the hierarchal management review progress, funding and resource allocation at frequent intervals and ensure that an adequate level of effort is being maintained,
- c. arrangements be made for a continuity of technical logic over an initial minimum period of five years,
- d. provision be made for continuous review of activities at the level at which technical direction is applied to ensure changes necessary to maintain direction and momentum are made.

11. The proposals in c and d above introduce the notion of a project technical director applying substantial expertise to the project over a period of some five years. It is acknowledged that this is a difficult goal to achieve, it is important to the success of the project however that the principle be accepted and some substantial effort be made to achieve at least an approximation to this requirement.

SECTION 9

CONCLUSION

1. The study is based on the premise that it is necessary for the Canadian Forces to achieve a high level of tactical mobility in the region extending northwards from about two hundred miles south of the treeline to the limits of Canadian sovereignty. The area embraces some of the most difficult terrain in the world which coupled with extreme seasonal variations creates an environment which is unique to Canada.
2. While it is possible to acquire some equipment based on earlier Canadian development from sources outside Canada and significant advance in technology for vehicles to be employed in the unique Canadian environment must come from within Canada.
3. At the outset it is necessary to identify the equipment requirements in precise measurable terms so that concepts may be evaluated and compared in terms of vehicle performance in specified terrain. Mobility prediction systems which claim to possess this capability exist and must be evaluated against the Canadian environment. It seems probable that a simpler system based on analytical comparison of the performance of the candidates with a standard vehicle will be required.
4. Development of equipment at best is an expensive time consuming process. The development of equipment based on little or no previous technology is likely to be excessively expensive and time consuming

as the technology is developed by trial and error during the development program. To develop equipment, therefore, it is necessary to provide a technology base which embodies the state of art in the particular field of endeavour.

5. There is an extensive technology in the field of ground mobility which is expressed in published material and data stored in libraries and data banks; much of this is applicable to the Canadian requirement. A check of the DSIS data bank produced about 50% of relevant material known to the (experienced) observer, it also produced some unknown to the observer. It is apparent that further activity is necessary to produce a reasonably complete state of art base in mobility technology.
6. The notion of creating a data base which is an expression of the state of art in mobility technology with particular reference to the Canadian environment emerges. The state of art is known to be incomplete or inadequate in many areas and a technology development program will be required to extend and complete it. The development program which has been proposed concentrates primarily on the two basic areas most likely to provide advances in capability, vehicle form and vehicle terrain interaction. The combination of the extended data base and the experience gained in the development program constitutes a technology base for further activities.
7. The co-operation of industry in the development program is highly desirable and the potential of industry for participation in this activity and any future equipment programs should be determined at

an early stage.

8. It is likely to take about five years at optimum rate of activity to produce substantial progress towards the creation of a technology base. In implementing the program great care must be taken to maintain the impetus and direction throughout this period.

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